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MAY 79 F A VASSALLO, K W GRAVES, D E ADAMS DAAA21-77-C-0046
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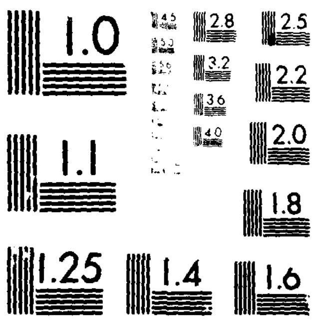

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K.W. GRAVES
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An experimental investigation of the thermal and erosion performance of a number of modifications to the M456A1 105mm round was conducted. An unfired 105mm M68 cannon was instrumented with special removable thermal and erosion sensors capable of distinguishing differences between charges using only a few shots. The instrumented tube was shipped to ARRADCOM, Dover, for completion of firing tests.

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A number of modifications to the M456A1 round were selected by ARRADCOM for test. These included variations in additive construction, type, deployment, or amount as well as change in projectile obturation. Calspan's silicone ablative material was included among the additive types tested.

It was found that while all additive types and deployments improved the thermal/erosion performance of the round compared with that containing no additive, best performance was obtained with the ablative configurations. For those, essentially no erosion was noted.

Within the additive liner types, results suggest best performance from those containing talc rather than TiO_2 and placed as far forward in the case as is possible. A ranking of all charges tested is given in the report.

FOREWORD

This report was prepared by Calspan Corporation, Buffalo, New York, in partial fulfillment of work conducted under Contract No. DAAA21-77-C-0046. The work was sponsored by the Propellants and Explosives Applications Branch of the Ammunition Development and Engineering Directorate, ARRADCOM.

Acknowledgement is given to Mr. Joseph Kocur and the gun crew of the Test Station, ARRADCOM (Dover, N.J.), without whose capable efforts completion of the test phase could not have been performed. Special thanks are given to Mr. Joseph McDonald for his efforts in setting up and operating the data recording instruments at the test station.

Of course, the vital efforts of Messrs. Seymour Lader and Kenneth Russell of ARRADCOM in the areas of logistical support, charge designs and technical guidance, and of Dr. Joseph Lannon in the area of wear and erosion are also acknowledged.

OBJECTIVE

The objective of the work was to evaluate tube wear effects of various 105mm charges through limited firings of each combined with the use of special removable erosion and thermal sensors. It is a further objective to use the results of such limited tests as a guide for selection among various ammunition modifications for minimizing wear in the 105mm M68 gun tube.

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1. INTRODUCTION

The evaluation of the effects of ammunition modifications on service life of large caliber tubes is normally a very costly procedure because of the large number of rounds that need to be fired before conclusive results are obtained. The normal procedure for determining cannon bore wear life is to initially compare similar systems on a theoretical or judgmental basis. Then large numbers of rounds are fired to produce a test for verification. This method is proven to be deficient in many respects, particularly with regard to cost, time, and ammunition expenditures.

Calspan Corporation has developed an effective method for generating erosion and heating data while firing a very few rounds of ammunition. Application of the techniques to large caliber guns has been successfully demonstrated in the past several years in the 8" howitzer[1] and then more recently for improving the XM201E2 charge for the 155mm gun.[2] Similar success was anticipated in diagnosing the erosion problem of the 105mm M68 gun. This gun experiences a secondary wear problem. That is, in addition to a reasonably high wear rate at the origin of rifling, a secondary wear, believed to be initiated by the M456 round, occurs anywhere between 2 and 25 inches from the origin of rifling. This secondary wear can cause ammunition malfunctions especially with the kinetic energy sabot rounds.

For the present work, the aforementioned special technique for measuring heating and erosion utilizing special removable thermal and erosion sensors was applied. These sensors normally have sufficient sensitivity to be able to screen various ammunition configurations for minimal erosion with very limited firings (e.g., <10 shots). In this manner, the selection of various wear reducing configurations becomes feasible. This report describes the test preparations, test scope and procedures, and test results obtained.

2. TEST PREPARATIONS

The study employed an experimental-analytical approach in which firing data provided a basis for judgement concerning magnitude of erosion/wear conditions in the tube and the efficacy of selected ammunition modifications toward reducing wear. The experimental work required the fabrication of suitable thermal/erosion instrumentation.

A. Tube Instrumentation

The M68 tube instrumentation consisted of the installation of ports for the insertion of thermal and erosion sensors. Figure 1 shows the location for each instrument sensor in the gun tube in terms of axial station and circumferential position relative to the 12 o'clock position. Three axial stations are instrumented. These are at 25, 26.5, and 35 inches from the rear face of the tube. These correspond to the origin of rifling and 1.5 and 10 inches downbore from the origin of rifling. These were selected because the origin of rifling is normally the location of greatest erosion, the 26.5 inch station represents an approximation of least erosion before a secondary wear position located at 35 inches.

At the origin (Section A-A of Figure 1), the instrument holes are clustered around the three o'clock position. An erosion sensor is placed in the groove just below the three o'clock position. An in-wall thermocouple is aligned with the next groove immediately above three o'clock, and an erosion sensor is placed in the second land above the three o'clock position.

At the 1.5 inch station (Section B-B), an in-wall thermocouple is aligned with the groove just below the three o'clock position and also two grooves up from there. In the groove between the two in-wall thermocouples is an erosion sensor.

At the 10 inch station (Section C-C), an erosion sensor is placed in the nearest groove at the side of the 12 o'clock position and an in-wall thermocouple is aligned with the groove at the other side.

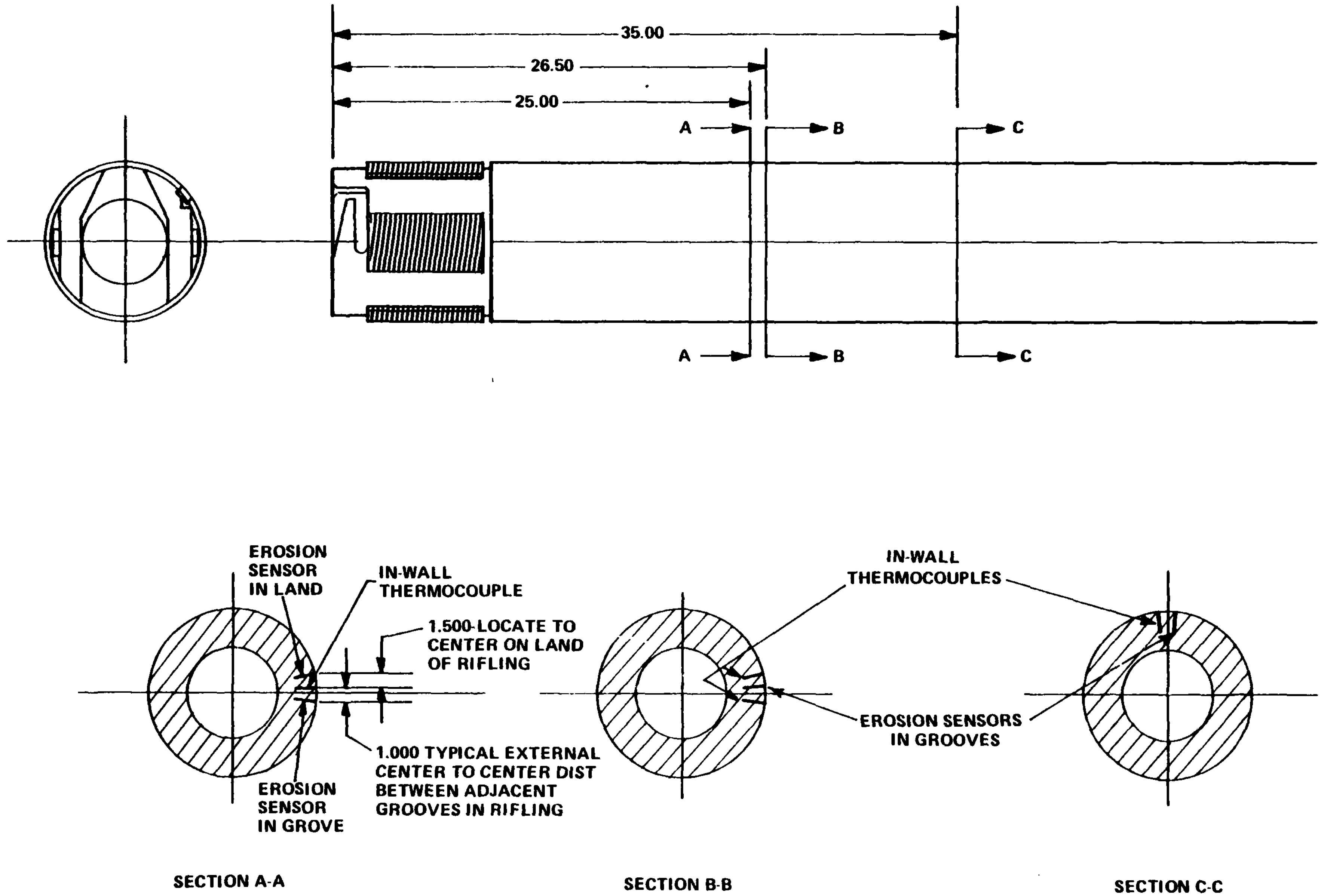


Figure 1 LOCATION OF INSTRUMENTATION FOR 105mm - M68 GUN TUBE

The flat bottom drilled in-wall thermocouple wells were each placed along the tube at the designated axial stations to a measured depth of nominally 0.040 inches from the bore surface at the center of a groove. Actual thermocouple depths were determined after drilling by direct measurement.

B. Thermal and Erosion Sensors

The thermocouple installation used for determination of tube heating is as shown in Figure 2. Stainless sheath 40 gage chromel-alumel thermocouple wires are forced into contact with the flat bottomed hole by the action of a compression spring. When contact is maintained, electrical output from the thermocouple is at the contact points of the wires with the tube wall, or the bottom of the well. If contact is lost for any reason, there will be no output. Thus, when the output is generated, it is assured to directly represent temperature at the contact point, which, through later analytical methods, yields the local amount of heat input per square foot of bore surface. As shown in Figure 2, a small amount of silicone grease was placed into the thermocouple well prior to insertion of the thermocouple to fill void spaces and decrease the small thermal resistance introduced by the presence of the hole. Finally, the thermocouple assembly was held in place simply by use of a 10-32 machine screw which also imposes the required load on the thermocouple.

The erosion sensor installations applied to the lands and grooves are shown in Figures 3 and 4. At the origin of rifling both land and groove sensors were used; at the downbore stations, only groove installations were used. Each sensor installation is comprised of two chief components: 1) a sensor holder, and 2) an erosion sensor sample. Because significant erosion per shot was anticipated, accurate placement of erosion sensor samples contoured to conform to the tube curvature during the entire test series required the fabrication of special removable erosion sensor holders. For the groove, the sensor holder made from 4340 steel, was designed to contain the contoured erosion sensor sample with means for adjusting surface match between sample and holder. Provision was also made to firmly fix the sample

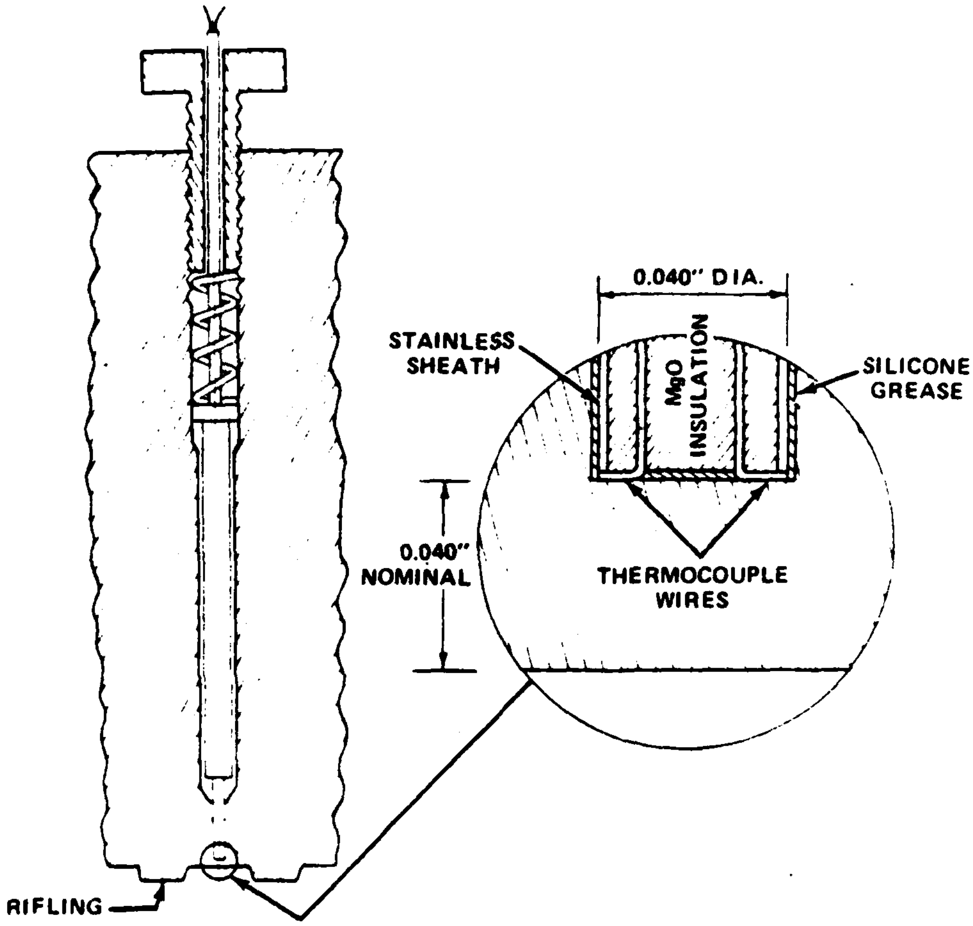


Figure 2 IN-WALL THERMOCOUPLE INSTALLATION

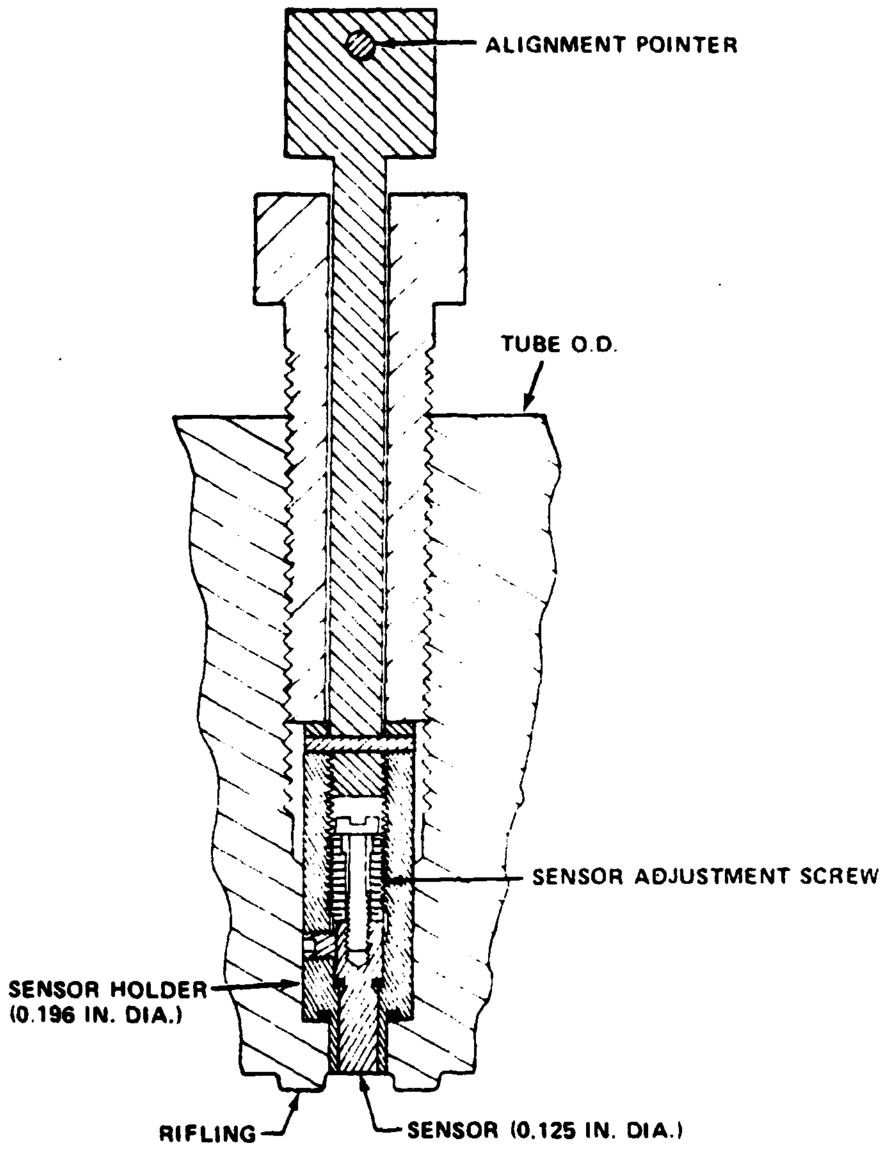


Figure 3 EROSION SENSOR INSTALLATION AT GROOVES

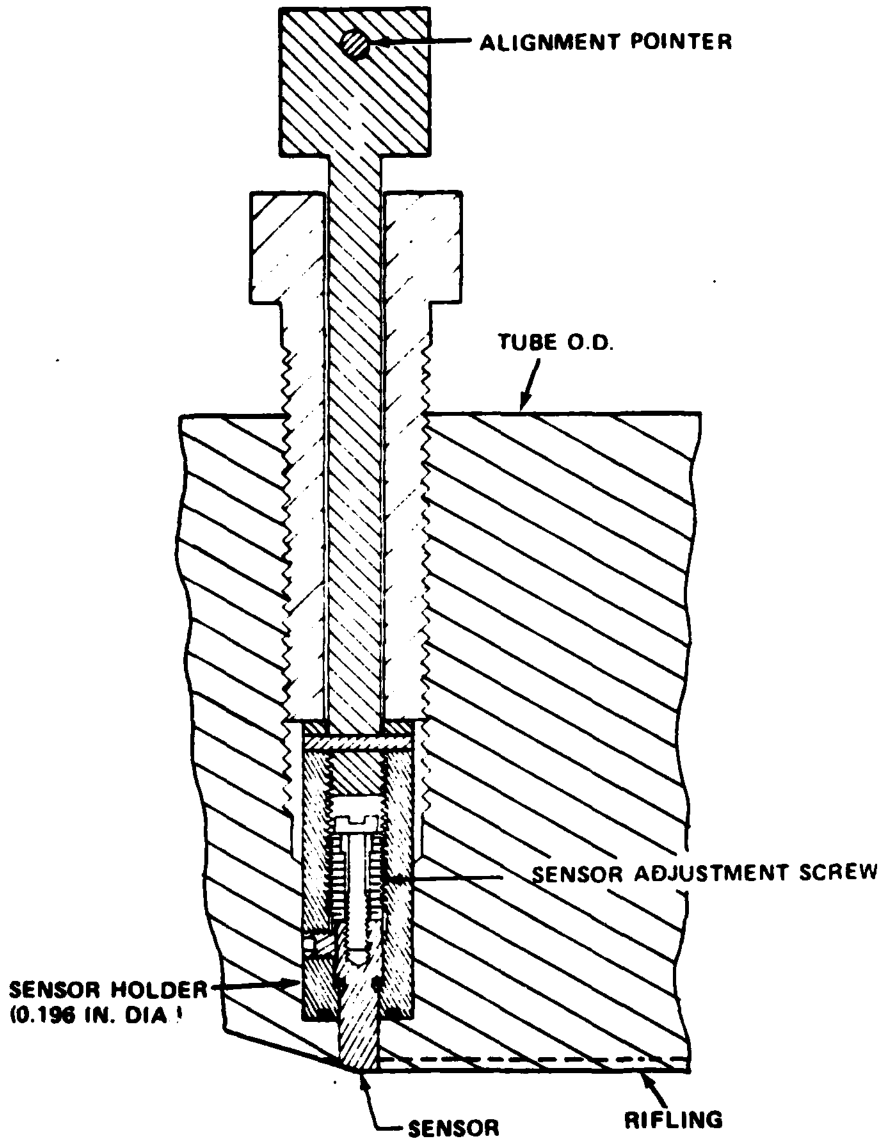


Figure 4 EROSION SENSOR INSTALLATION IN RIFLING

into position after adjustment. Each holder after fabrication was inserted into its respective location in the tube and honed to produce an excellent fit to the bore curvature. Gas seal during firing was provided by use of conventional "O" rings as shown in Figure 3.

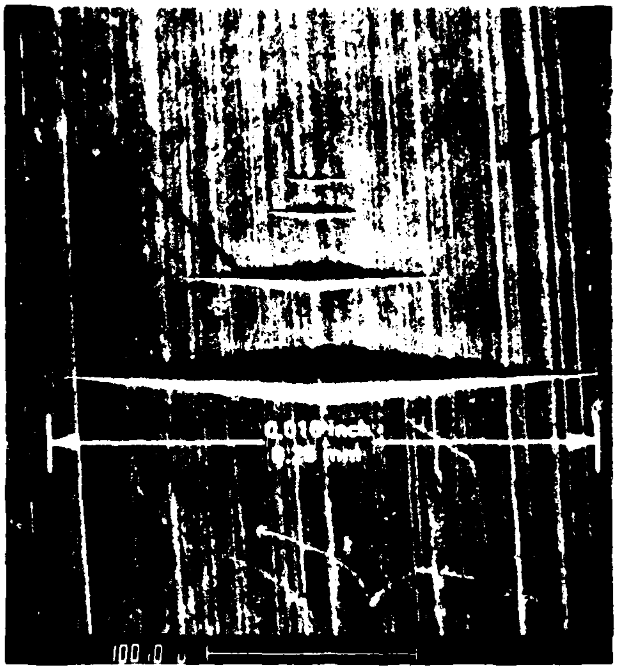
For the land, the 4340 sensor holder was cut back as shown in Figure 4 so that the erosion sensor could project to the bore through the land. These sensors were adjusted for position in the holder using a specially prepared fixture which matched the dimensions of the original sensor installation in the tube.

The erosion sensors were machined in the typical shape of cylinders having a single "O" ring groove at the approximate mid-point (see Figures 3 and 4). Sensors were made to be insertable as needed at the origin or downbore stations. Threaded holes were tapped into the sensor afterbody to fix the sensor in place as were positioning flats to maintain correct orientation of surface contour. The surface of each sensor was contoured to 4.1 inch diameter as an acceptable match to that of the holder or tube. This face, after polishing the surface contour, was fitted with a series of impressions made using a microhardness tester. A typical pattern of impressions is shown in Figure 5. Variation in impression length as shown was obtained by changing the load on the microhardness tester.

Those sensors, fabricated for placement in the lands at the origin of rifling, required a break in the surface contour to match the ramp-followed-by-plateau which exists at that specific location in the tube.

A diamond indenter of the "Knoop" type was employed in all sensors. This indenter configuration produces a sharp impression with a constant ratio of length to depth of 30:1, independent of load. The impressions serve as a gauge by which erosion or wear may be measured after firing. The approximate depths of the Knoop impressions on each sensor ranged from 50 to 300 microinches.

KNOOP IMPRESSIONS
30:1 LENGTH-TO-DEPTH



SURFACE
POLISH
MARKS

MAG = 300X

Figure 5 TYPICAL EROSION SENSOR SURFACE SHOWING ARRANGEMENT OF KNOOP IMPRESSIONS

After application of surface impressions, the surface of each sensor was characterized prior to test by photomicrographs taken using the Scanning Electron Microscope (SEM) at 300 times magnification. Finally, each sensor was weighed using an analytical balance.

Post-test examination of the erosion sensors indicates the amount of erosion in several possible ways. First, when gross erosion occurs, eliminating all impressions, total weight loss gives direct measure of material loss. Second, when severe erosion occurs, one or several impressions may be completely removed, thus indicating surface loss. Third, when minor erosion occurs, the impression lengths will shorten in direct proportion to depth change. Finally, very minor erosion is indicated by removal of surface polishing marks which are only a few microinches deep.

3. GENERAL TEST SCOPE AND PROCEDURES

A. Test Scope

Heat transfer and erosion data were obtained in a total of 127 test firings conducted at Picatinny Arsenal with Calspan personnel in attendance. General test procedure was to load and fire test charges at a rate governed by required recording of thermal data and installation of erosion sensors. Typically, 10 to 15 minutes elapsed between test shots. At this firing rate, steady state temperature of the tube was only a few degrees above ambient and was not an influencing factor on erosion or heat input data derived.

In the test firing series, typical measurements included: 1) chamber pressure, 2) tube in-wall temperatures, 3) bore erosion, and 4) projectile velocity.

Test rounds of a specific type (test series) were fired consecutively. After each test series involving charges containing erosion reducing additives, one M456A1 round without liner was fired as a cleaning round. Its purpose was to reduce the possible carryover of the effect of the additive to the following test series. Heating data were routinely gathered for these cleaning charges as an additional control. Such cleaning rounds were also fired at the beginning of each day's testing. All charges were preconditioned at 70°F.

B. Data Reduction

Major data reduction in this investigation involved conversion of in-wall thermocouple outputs to total bore heat input per square foot and assessment of amount of erosion indicated by examination of appropriate erosion sensors.

Two methods were used to convert thermocouple output to bore heat input. The first is based upon the theory derived in Reference 3 where it is shown that bore heat input per square foot is given by the expression:

$$Q = \Delta T(\Theta) \sqrt{\pi K C \rho \Theta} \qquad (1)$$

where Q is the bore heat input - $\frac{Btu}{Ft^2}$

$\Delta T(\Theta)$ is the indicated change in in-wall temperature at time Θ

K is the thermal conductivity

$c\rho$ is the heat capacity per unit volume

Θ is the time after firing

Data reduction procedure is to apply Equation (1) at successive time intervals of 0.1, 0.2, 0.3 sec., etc., thus resulting in a plot of Q vs. Θ. The curve thus produced will be nearly asymptotic to the desired heat input.

A second and simpler method makes use of the theory of Reference 4 in which it is shown that the bore heat input is given by

$$Q = C\rho\delta \, \Delta T_{max} \sqrt{\frac{e\pi}{2}} \qquad (2)$$

Here, ΔT_{max} is the maximum temperature rise indicated by the thermocouple

e is the base of natural logarithms (2.7182)

δ is the distance from the bore surface to the thermocouple

Each of the above methods has both desirable and undesirable features. The first is very insensitive to thermocouple depth, although for this tube, requires that distance be less than 0.050 inches. Accuracy reduces as this distance is increased. Data reduction involves analysis of the entire temperature-time history for the thermocouple and this is laborious.

The second method is obviously insensitive to material thermal conductivity but this is counterbalanced by need for precise knowledge of thermocouple location. The single point measurement feature of this method does render it more suitable for many measurements than the first.

Although both methods were used successfully in initial data reduction, it was found that more consistent heat input values were obtained using the first method above. Therefore, heat input data reported are a result of the application of this method.

The amount of erosion experienced by each sensor was determined by comparison of its pretest and post-test SEM photographs. This comparison was made after careful ultrasonic cleaning as confirmed by use of the SEM in the x-ray mode, and involved visual study of surface condition and measurement of impression length change. Representative photographs of erosion sensors taken after testing are presented in a later section.

4. TEST RESULTS

A. Ammunition

A brief description of the test rounds evaluated in the firing program is given in Table 1. These rounds were selected to explore the influence on heating and erosion through modifications or changes in:

1. Additive construction
   Series 1 and 2

2. Additive type and/or deployment
   Series 3, 4, 18, and 19

3. Additive type and/or amount
   Series 5,6,7,8,9,10,11,12,18, and 19

4. Silicone ablative configurations
   Series 13, 14, 19, 20, 21, and 22

5. Projectile obturation
   Series 15, 16, 17, and 17'

Details of each round including series number, sample size, type, amount, and deployment of additive, obturator, and other pertinent remarks are given in Table 1.

In general, the additive types were placed at the case mouth in conventional manner except where noted. The ablative types designed by Calspan were attempts to inhibit erosion using a silicone mix consisting of 92% 60,000 CSTK dimethyl silicone, 7.5% fumed silica, and 0.5% Triton X wetting agent. The ablative composition was added to the round during loading. It was placed at the case mouth around the projectile boom behind the obturator. Essentially three ablative configurations were tested: First, the ablator was enclosed by a polypropylene capsule which was fitted to the projectile boom prior to insertion into the case. Second, the ablator was placed as a loose fill into the annular region between boom and case with a polypropylene diaphragm separating it from the propellant. Third, the ablator was housed within a latex balloon placed around the projectile boom prior to insertion into the case. A urethane sponge separator between

TABLE 1. TEST ROUND DESCRIPTION

456A1 Cartridge

Series No.	Sample Size	Type, Amount, Deployment of Additive	Nylon Obturator	Remarks
0	19	No additive	Old Design	Cleaner
1	9	STD Liner	Old Design	Baseline
2	4	Mylar on both sides of liner	Old Design	Baggy Type
3	4	STD Liner placed forward in case	Old Design	
4	5	STD Liner folded back on fin assembly boom	Old Design	
5	4	Double thick STD liner	Old Design	
6	7	Liner using Dupont LW Grade TiO_2	Old Design	
7	4	Liner using American Cyanamid Unitane 0220 TiO_2	Old Design	
8	4	Liner using National Lead Titanox 2005 TiO_2	Old Design	
9	4	Liner using Kerr McGee TiO_2	Old Design	
10	4	Polyurethane in lieu of STD liner	Old Design	
11	7	Liner with talc	Old Design	
12	7	Double thick liner with talc	Old Design	
13	7	3 in. ablative capsule 250 gms. ablator	Old Design	Forward in Case
14	7	3 In. Ablative disc 250 gms. ablator	Old Design	Forward in Case
15	4	Spin stabilized M489 projectile		M6 propellant
16	3	No liner	Old Design	Subloaded charge assessment
17	5	STD liner	New Design	
18	5	1 1/2 thick liner using Kerr McGee TiO_2	New Design	Liner forward

TABLE 1. TEST ROUND DESCRIPTION (Cont.)

Series No.	Sample Size	Type, Amount, Deployment of Additive	Nylon Obturator	Remarks
19	6	Double thick talc liner baggy type	Old Design	Liner forward
20	2	250 gms ablator in balloon, sponge separator	New Design	11 lb 8 oz propellant
21	4	250 gms ablator in balloon, sponge separator	New Design	11 lb 6 oz propellant
22	2	250 gms ablator in "thin" latex balloon, sponge separator	New Design	11 lb 3 oz propellant

the balloon containing the ablator and the propellant was also used in this variation. Placement of the ablative package into the round was not found difficult in any of these variations, although greatest ease of loading was found for that which employed the balloons.

B. Total Heat Input

Total heat input values determined for all shots are given in Table 2. Resulting average values are summarized in Table 3. As may be observed by reference to Table 3, the wear reducing additives generally reduce the bore heat input. The amount of reduction was, however, clearly influenced by type, amount, and placement of additive. Furthermore, for the additive charges taken as a group, there appears to be higher heat input at the secondary wear position than at the origin of rifling. For the charge containing the standard liner as well as for the majority of other charges, heat input shows to have a minimum point between the origin and secondary wear locations. Hence, the heat input profile along the tube generally follows the wear/erosion profile observed after multishot firings. Because wear/erosion also depends upon factors other than heating, for example, propellant gas surface shear stress, the bore heat input is not directly proportional to the loss at each station along the tube.

An examination of the heat input data suggests that a ranking of charges can be made with respect to their measured heat input. An initial ranking best-to-worst for the origin of rifling can be made based upon average heat input. This is shown in Table 4. Additionally, because one notes a general decrease in heating as shots are fired for each series, a second ranking can be made based upon the heat input for the last round of each series. This ranking is also shown in Table 4. Inspection of these two rankings shows them to be very compatible. If one further assumes each method of ranking to be equally valid, one can generate a composite ranking of each charge by averaging the above two rankings. The resulting composite ranking for heating at the origin of rifling is given in Table 5. The index value shown for each charge is simply the average of the two earlier rankings and serves as a measure of ranking differences between charges.

TABLE 2. 105MM HEAT INPUT DETERMINATIONS

Shot No.	Series No.	Description	Pressure $X10^{-3}$psi	Velocity Ft/Sec	Total Heat Input Btu/Ft^2 at Given Distance From Origin 0 in.	1.5 in.	10 in.
1	0	No liner	61.1	3855	109.8	98.0	102.7
2	1	STD with liner	62.7	3872	109.8	104.1	106.3
3			60.7	3933	---	---	---
4			62.9	3895	93.9	92.0	100.9
5			63.6	3893	99.2	92.0	102.7
6	0	No liner	59.2	3894	102.7	101.5	100.9
7	2	Mylar "baggy"	61.0	3808	99.2	95.4	102.7
8			62.9	3883	97.4	91.1	97.4
9			61.9	3875	97.4	86.8	97.4
10			63.2	3873	90.3	86.7	92.1
11	0	No liner	61.0	3845	100.9	98.9	104.5
12	3	Forward liner	60.6	3865	92.1	86.7	92.1
13			61.1	3803	90.3	86.8	99.2
14			62.8	3866	88.5	85.0	85.0
15			61.5	3872	86.8	84.1	79.7
16	0	No liner	59.1	3866	111.6	92.0	97.0
17	5	Double thick liner	61.2	3874	88.5	86.8	88.5
18			60.0	3828	97.4	90.2	99.2
19			63.8	3881	97.4	93.7	95.6
20			63.6	3897	93.9	89.3	92.1
21	0	No liner	58.7	3798	111.6	105.8	106.3
22	7	American Cyanamid TiO_2 liner	60.0	3797	97.4	95.4	100.9
23			62.3	3844	97.4	92.0	100.9
24			61.7	3802	97.4	96.3	106.3
25			61.6	3817	97.4	91.9	104.5
26	0	No liner	59.7	3812	111.6	106.3	116.9
27	8	National Lead TiO_2 liner	61.0	3840	97.4	96.6	100.9
28			61.9	3865	90.3	89.6	97.4
29			62.7	3873	90.3	89.6	97.4
30			60.1	3851	92.1	90.5	104.5
31	0	No liner	59.7	3794	111.6	106.3	106.3
32	9	Kerr McGee TiO_2 liner	61.3	3853	88.5	87.0	95.6
33			62.0	3868	81.5	81.7	90.3
34			60.3	3863	77.9	75.5	88.5
35			59.1	3878	69.1	71.2	58.6
36	6	Dupont LW grade TiO_2 liner	62.0	---	72.3	73.6	82.1
37			60.7	3854	95.3	93.0	97.5
38			60.2	3878	90.0	88.0	92.3
39			60.6	3826	93.5	93.7	102.3
40			62.3	3864	91.7	89.7	97.5
41			60.3	3780	91.7	95.4	99.2
42			62.1	3850	90.0	89.0	94.1
43			60.1	3851	88.2	93.7	95.8
44	0	No liner	58.9	3877	108.0	105.8	99.0
45	11	Talc liner	61.7	3861	95.6	90.8	95.6
46			60.8	3854	88.5	84.7	88.8
47			58.4	3858	92.1	93.1	97.3
48			60.6	3862	86.8	88.6	83.6
49			62.1	3866	77.8	86.8	85.4
50			61.9	3874	85.0	92.4	88.8
51			--	3859	83.2	89.5	90.5
52	0	No liner	59.7	3847	93.9	100.7	100.7
53	12	Double thick talc liner	62.3	3844	86.8	86.3	87.1
54			61.2	3789	85.0	84.3	---
55			62.0	3845	81.5	82.1	85.4
56			61.0	3868	88.5	83.1	90.5
57			62.3	3849	77.9	76.8	81.9
58			62.1	3841	76.1	73.8	81.9
59			60.6	3846	72.6	70.4	76.8

TABLE 2. 105MM HEAT INPUT DETERMINATIONS (CONT.)

Shot No.	Series No.	Description	Pressure $X10^{-3}$psi	Velocity Ft/Sec	Total Heat Input Btu/Ft^2 at Given Distance From Origin 0 in.	1.5 in.	10 in.
60	0	No liner	60.0	3788	99.2	97.9	100.7
61	10	Polyurethane liner	--	3850	102.7	97.0	100.7
62			60.7	3814	102.7	99.6	97.3
63			60.5	3818	95.6	97.4	100.7
64			62.9	3873	90.3	87.7	100.7
65	0	No liner	57.8	3795	118.2	127.2	---
66	4	STD liner folded	60.1	3809	118.2	122.2	---
67		back on boom	61.7	3841	90.0	91.5	92.3
68			61.4	3818	90.0	91.3	87.2
69			62.3	3813	84.7	87.2	87.2
70			60.3	3808	90.0	86.2	95.8
71	16	Subloaded charge	--	3510	88.2	84.1	83.9
72		assessment rounds	67.3	3647	79.4	81.7	78.7
73		M6 propellant	64.2	3595	91.7	81.9	88.8
74	15	Spin stabilized M489	62.9	3642	75.9	72.4	68.4
75		projectile subloaded	68.2	3671	72.3	66.9	70.1
76		charge M6 propellant	67.2	3652	74.1	64.4	73.5
77			66.2	--	65.3	58.2	59.9
78	0	No liner	60.6	3816	104.6	100.4	100.8
79	13	3" ablative capsule	64.0	3861	76.2	83.1	88.9
80		250 gms ablator	65.6	3859	88.6	94.4	76.9
81			63.8	3879	65.6	76.1	87.2
82			65.4	3871	62.0	76.4	85.5
83			64.1	3856	58.5	69.9	90.6
84			63.4	3873	54.9	63.6	80.3
85			65.8	3876	58.5	65.5	73.5
86	0	No liner	59.7	3771	79.8	87.1	100.8
87	14	3" ablator disc	61.9	3791	70.9	78.5	90.6
88		250 gms ablator	60.3	3797	70.9	74.8	90.6
89			61.5	3850	70.9	69.9	83.8
90			64.0	3861	53.2	67.3	83.8
91			60.8	3788	49.6	65.8	82.0
92			62.0	3787	46.1	65.0	68.4
93			58.4	3724	46.1	64.4	68.4
94	0	No liner	58.6	3821	85.5	95.7	99.8
95	17	STD liner	52.6	3714	82.4	80.5	83.2
96		new obturator	52.0	3719	77.8	85.1	80.1
97		different propellant	52.0	3709	80.9	80.5	84.7
98		web	52.3	3695	77.8	85.1	83.2
99			51.5	3709	76.3	80.5	83.2
100	0	No liner	59.3	3782	---	110.9	125.5
101	17'	Series 17 with	48.1	3605	91.1	97.2	102.8
102		old obturator	50.9	3655	98.7	95.7	98.3
103			51.2	3685	85.1	95.7	92.2
104			51.4	3629	88.1	97.2	99.8
105			51.3	3663	85.1	95.7	93.7
106	0	No liner	59.5	3786	86.6	115.4	107.4
107	18	1 1/2 thick Kerr McGee	62.8	3872	77.3	89.6	87.7
108		liner	60.3	3861	94.2	92.7	83.2
109			61.6	3846	79.0	80.5	75.6
110			61.3	3842	79.0	82.0	77.1
111			62.8	3876	82.0	83.5	77.1
112	0	No liner	59.3	3788	100.7	107.4	108.9
113	19	Double liner with talc	62.1	3851	79.4	84.7	83.8
114		"baggy" type forward	62.7	3850	80.9	86.2	88.3
115			62.8	3843	73.2	80.1	77.8
116			64.0	3858	68.7	72.6	77.8
117			62.7	3848	73.2	74.1	80.8
118			62.8	3860	68.7	68.0	76.3
119	0	No liner	61.6	3868	100.7	98.3	95.8
120	20	250 gms ablator in	63.6	3897	70.2	78.6	79.3
121		balloon, sponge separator	63.4	3878	50.4	62.0	82.3
122	21	250 gms ablator in	62.5	3873	50.4	59.0	73.4
123		balloon, sponge separator	63.0	3879	64.1	59.0	67.4
124			63.8	3831	54.9	57.5	61.4
125			62.6	3860	47.3	51.4	62.9
126	22	250 gms ablator in thin	59.1	3793	44.3	52.9	56.9
127		latex balloon, sponge separator	59.2	3812	48.8	51.4	56.9

TABLE 3. 105MM TEST RESULTS, AVERAGES

Series No.	Type	Pressure psi	Velocity Ft/Sec	Average Heat Input - Btu/Ft^2 At Given Distance From Origin of Rifling: 0 Inches	1.5 Inches	10 Inches
0	No liner	59,600	3822	106.9*	103.4*	103.2*
1	STD liner	62,400	3898	100.9	96.0	103.3
2	Mylar "baggy"	62,250	3859	96.0	90.0	97.4
3	Dbl fwd talc liner	61,500	3851	89.4	85.6	89.0
4	Liner folded on boom	61,100	3817	94.5	95.6	90.6
5	Dbl thick liner	62,100	3870	94.3	90.0	93.9
6	Dupont LW grade TiO_2	61,000	3843	89.0	89.5	95.1
7	Am. Cymd. TiO_2 liner	61,400	3815	97.4	93.9	103.1
8	Nat. Lead TiO_2 liner	61,400	3857	92.5	91.5	100.0
9	Kerr McGee TiO_2	60,600	3865	79.2	78.8	90.7
10	Polyurethane liner	61,200	3838	97.8	95.4	99.9
11	Talc liner	60,900	3862	87.0	89.4	90.0
12	Dbl thick talc liner	61,600	3840	81.2	79.5	83.9
13	250 gms ablative capsule	64,500	3867	66.3	75.5	83.2
14	250 gms ablative 3" disc	61,200	3799	58.2	69.3	81.0
15	M489 proj. M6 prop.	66,100	3655	71.9	65.4	67.9
16	Subloaded M6 prop.	65,700	3584	86.4	82.5	83.8
17	STD liner, new obturator	52,000	3709	79.0	82.3	82.9
18	1 1/2 thick Kerr McGee	61,800	3859	82.3	85.6	80.1
19	Dbl fwd talc liner	62,800	3851	74.0	77.6	80.8
20 21 22	250 gms ablator in latex balloon	62,100	3855	53.8	58.9	67.5

*Excluding all rounds following ablative rounds

TABLE 4 RANKING[1] BASED UPON HEAT INPUT AT ORIGIN OF RIFLING

Ranking Best-to-Worst	Based Upon Average Heat Input (Btu/ft^2)		Based Upon Last Recorded Heat Input (Btu/ft^2)	
	Series	Heating	Series	Heating
1	20/21/22	53.8	14	46.1
2	14	58.2	20/21/22	48.8
3	13	66.3	13	58.5
4	19	74.0	19	68.7
5	9	79.2	9	69.1
6	12	81.2	12	72.6
7	18	82.3	18	82.0
8	11	87.0	11	83.2
9	6	89.0	3	86.8
10	3	89.4	6	88.2
11	8	92.5	4	90.0
12	5	94.3	2	90.3
13	4	94.5	10	90.3
14	2	96.0	8	92.1
15	7	97.4	5	93.9
16	10	97.8	7	97.4
17	1	100.9	1	99.2
18	0	106.9	0	106.9[2]

[1]Excluding series 15, 16, 17 and 17' (see Table 2) as being not comparable to the others.

[2]Taken as the average for this charge because only one shot groups were fired.

TABLE 5 COMPOSITE RANKING BASED UPON HEAT INPUT AT THE ORIGIN

Ranking Best-to-Worst	Index	Series	Type
1	1.5	14	250 gms Ablator 3" Disc
2	1.5	20/21/22	250 gms Ablator in Balloon
3	3	13	250 gms Ablative Capsule
4	4	19	Dbl Forward Talc Liner
5	5	9	Kerr-McGee TiO_2 Liner
6	6	12	Dbl Thick Talc Liner
7	7	18	1 1/2 Thick Kerr-McGee Liner
8	8	11	Talc Liner
9	9.5	3	Forward Liner
10	9.5	6	DuPont LW Grade TiO_2
11	12	4	Std Liner Folded on Boom
12	12.5	8	National Lead TiO_2 Liner
13	13	2	Mylar "Baggy"
14	13.5	5	Dbl Thick Liner
15	14.5	10	Polyurethane Liner
16	15.5	7	American Cyanamid TiO_2 Liner
17	17	1	Std Liner
18	18	0	No Liner

A similar ranking procedure was followed for heating at the secondary wear station. Results are as presented in Tables 6 and 7.

From a review of the composite rankings of Tables 5 and 7, the ablative charges clearly rank best. Following the ablative charges, it appears that both increasing the amount of liner and use of talc in place of TiO_2 is effective. Also, a forward liner placement is preferred. Among the TiO_2 types the Kerr-McGee appears to perform best with the American Cyanamid TiO_2 least effective. The polyurethane liner shows some but minor improvement over that of the standard liner.

C. Tube Erosion

Examination of the erosion sensors after test shows nearly all charge modifications to improve erosion performance over that of the charge containing no additive. A ranking of charge types along with their estimated loss/shot is given in Table 8 for the origin of rifling station and in Table 9 for the secondary wear station. At both locations rounds containing ablator performed best although the differences between the ablative charges and those containing talc were not as great as the differences in observed heating indicated earlier. Furthermore, the rankings based upon erosion are not as sharply defined as those based upon heating due to difficulties in interpreting surface loss. Nevertheless the improved performance of the ablative rounds over that of the standard liner is very notable as shown in Figures 6 and 7 for the origin and secondary wear stations respectively. In each case, the sensors exposed to firings of rounds containing conventional additive showed obvious surface loss whereas those for the ablative series showed essentially no loss. Sensors exposed to firings of the other charge series showed losses between these extremes in accordance with the loss values of Tables 8 and 9.

At the minimum wear station (Station B), little erosion was observed for all charges containing additive. Of the series tested at this station (0, 1, 2, 3, 5, 6, 7, 8, 9, and 11), the charge containing the standard liner showed least improvement over that of charges containing no

TABLE 6 RANKING[1] BASED UPON HEAT INPUT AT SECONDARY WEAR STATION

Ranking Best-to-Worst	Based Upon Average Heat Input (Btu/ft^2)		Based Upon Last Recorded Heat Input (Btu/ft^2)	
	Series	Heating	Series	Heating
1	20/21/22	67.5	20/21/22	56.9
2	18	80.1	14	68.4
3	19	80.8	13	73.5
4	14	81.0	19	76.3
5	13	83.2	12	76.8
6	12	83.9	18	77.1
7	3	89.0	3	79.1
8	11	90.0	9	88.6
9	4	90.6	11	90.5
10	9	90.7	5	92.1
11	5	93.9	2	92.1
12	6	95.1	4	95.8
13	2	97.4	6	95.8
14	10	99.9	10	100.7
15	8	100.0	1	102.7
16	7	103.1	0	103.2[2]
17	0	103.2	8	104.5
18	1	103.3	7	104.5

[1] Excluding series 15, 16, 17, and 17'.

[2] Taken as the average for this charge because only one shot groups were fired.

TABLE 7 COMPOSITE RANKING BASED UPON HEAT INPUT AT SECONDARY WEAR STATION

Ranking Best-to-Worst	Index	Series	Type
1	1	20/21/22	250 gms Ablator in Balloon
2	3	14	250 gms Ablator 3" Disc
3	3.5	19	Dbl Forward Talc Liner
4	4	13	250 gms Ablative Capsule
5	4	18	1 1/2 Thick Kerr-McGee Liner
6	5.5	12	Dbl Thick Talc Liner
7	7	3	Forward Liner
8	8.5	11	Talc Liner
9	9	9	Kerr-McGee TiO_2 Liner
10	10.5	5	Dbl Thick Liner
11	10.5	4	Std Liner Folded on Boom
12	12	2	Mylar "Baggy"
13	12.5	6	DuPont LW Grade TiO_2
14	14	10	Polyurethane Liner
15	16.0	8	National Lead TiO_2 Liner
16	16.5	1	Std Liner
17	16.5	0	No Liner
18	17	7	American Cyanamid TiO_2 Liner

TABLE 8 RANKING BASED UPON EROSION AT THE ORIGIN OF RIFLING

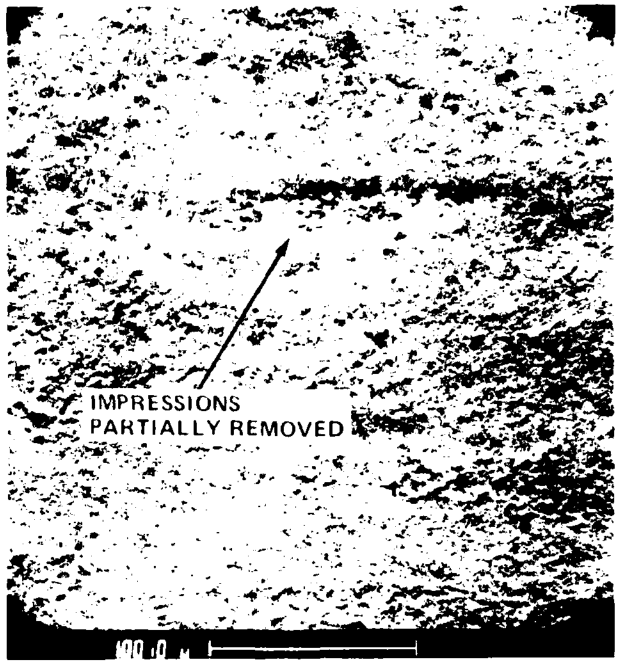
Ranking Best-to-Worst	Series	Type	Estimated Loss/Shot Microinches/Shot
1	20-21-22	250 gms Ablator Balloon	0.5
2	2	Mylar "Baggy"	2
3	13	250 gms Ablator Capsule	2.5
4	11	Talc Liner	3
5	19	Dbl Forward Talc Liner	5
6	14	250 gms Ablative Disc	7
7	8	National Lead TiO_2	7
8	12	Dbl Thick Talc Liner	7.5
9	3	Forward Liner	9
10	6	DuPont LW Grade TiO_2	10
11	9	Kerr-McGee TiO_2	11
12	18	1 1/2 Thick Kerr-McGee	11
13	10	Polyurethane Liner	15
14	4	Std Liner Folded on Boom	16
15	5	Dbl Thick Liner	17
16	7	American Cyanamid TiO_2	25
17	1	Std Liner	60
18	0	No Liner	300

TABLE 9 RANKING BASED UPON EROSION AT THE SECONDARY WEAR STATION

Ranking Best-to-Worst	Series	Type	Estimated Loss/Shot Microinches/Shot
1	13	250 gms Ablative Capsule	2
2	14	250 gms Ablative Disc	5
3	6	DuPont LW Grade TiO_2	6
4	20-21-22	250 gms Ablator Balloon	7
5	4	Std Liner Folded on Boom	7
6	11	Talc Liner	8
7	19	Dbl Forward Talc Liner	11
8	5	Dbl Thick Liner	12
9	10	Polyurethane Liner	12
10	8	National Lead TiO_2	15
11	9	Kerr-McGee TiO_2	20
12	18	1 1/2 Thick Kerr-McGee	20
13	12	Dbl Thick Talc Liner	35
14	2	Mylar "Baggy"	60
15	3	Forward Liner	70
16	7	American Cyanamid TiO_2	70
17	1	Std Liner	80
18	0	No Liner	300

REPRESENTS GREATEST EROSION

SERIES 0 NO ADDITIVE
AFTER 4 SHOTS



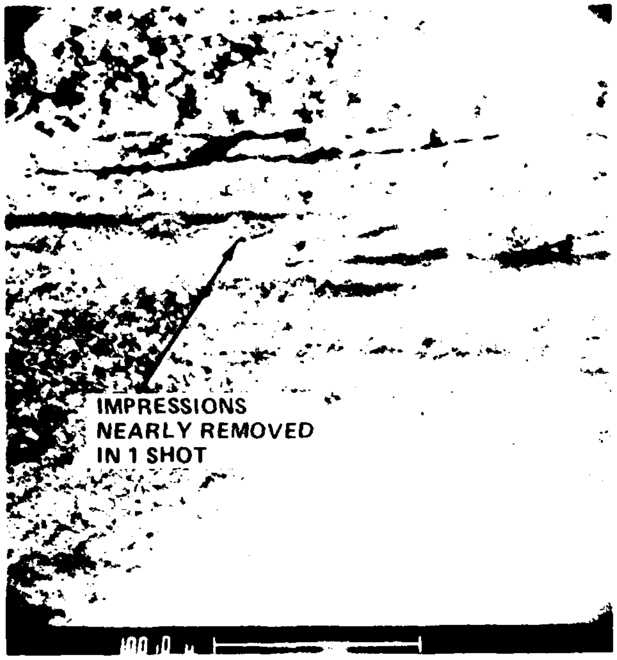
REPRESENTS CURRENT ROUND

SERIES 1 STD LINEAR
AFTER 4 SHOTS

REPRESENTS LEAST EROSION

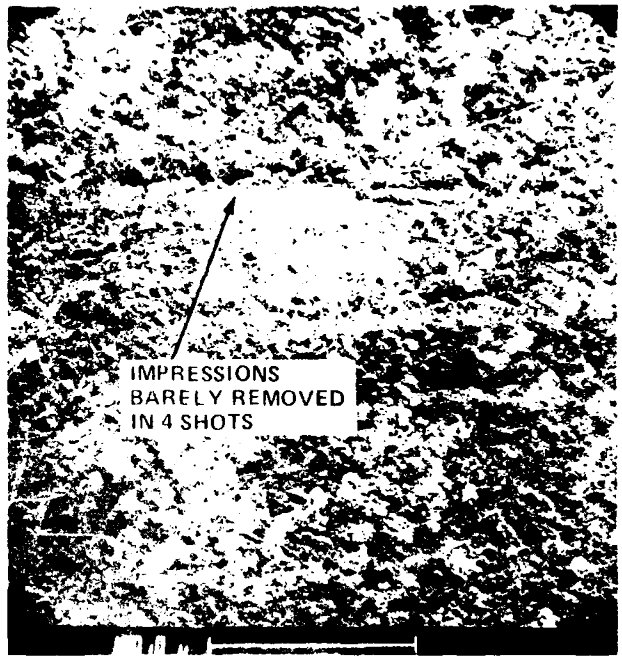
SERIES 20/21/22 ABLATOR IN BALLOON
AFTER 8 SHOTS

Figure 6 SURFACE CONDITION OF SELECTED SENSORS AT THE ORIGIN AFTER TEST (CLEANED)



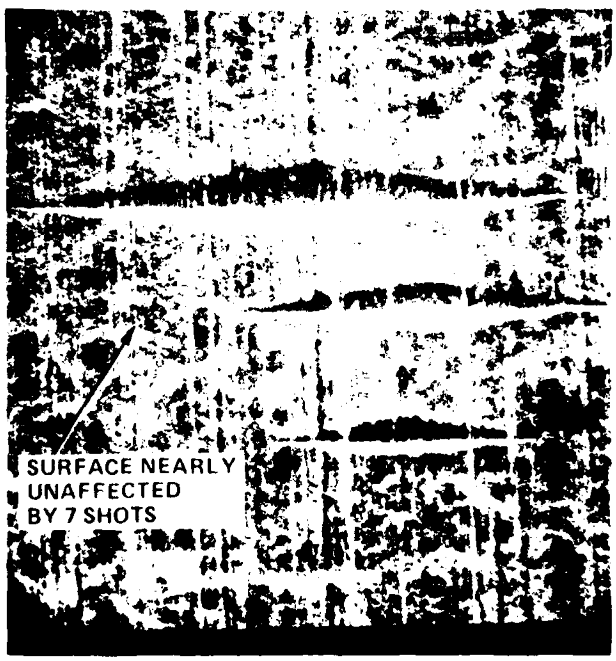
REPRESENTS GREATEST EROSION

SERIES 0 NO ADDITIVE



REPRESENTS CURRENT ROUND

SERIES 1 STD LINER



REPRESENTS LEAST EROSION
SERIES 13 ABLATOR IN CAPSULE

Figure 7 SURFACE CONDITION OF SELECTED SENSORS AT THE SECONDARY WEAR STATION AFTER TEST (CLEANED)

additive.* Figure 8 illustrates the typical improvement afforded by the additive through a comparison of sensor surface condition after test. Results suggest minimum erosion performance at this station in accordance with observations from field test data.

Tube erosion as indicated by sensors in the lands of the rifling (Station D) at the origin was found to generally be greater than that recorded in the groove at the same location. Of the charges tested at this location (series 0, 1, 2, 3, 5, 6, 7, 8, 9, and 11), best performance was obtained for charges containing the Kerr-McGee additive (series 9). This was followed closely by the forward liner (series 3). All other charges showed severe erosion. Figure 9 compares sensor surface condition after test for charges containing no additive, the standard additive, and the Kerr-McGee additive. These results suggest that additive type and/or deployment can certainly influence erosion of the rifling. Use of the erosion sensors can aid in establishing erosion differences between charges where meaningful (>5 microinches) differences exist.

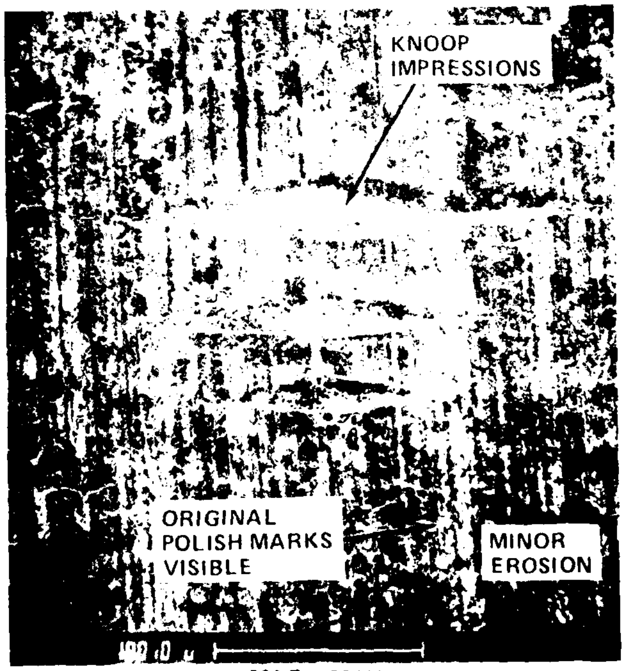
D. Heating/Erosion Correlation

The mechanism by which wear reducing additives affect material loss from the bore surface is as yet uncertain. Depending upon weapon and/or charge type, tube protection might be gained by one or more of several mechanisms. First, the wear additive may lower bore heating on the gas side as a result of a lowering of effective propellant gas temperature in the boundary layer; or by lowering the convective heat transfer coefficient. Second, the additive may lower bore heating by application of a thin insulative barrier on the bore surface. Third, the additive may interfere with chemical effects at the bore surface such as surface carburization or oxidation. Fourth, the additive may lower the friction force between projectile and tube. While it is possible that all of the above mechanisms in combination are responsible for improved wear life, present results suggest that additives act to affect

*Following the test firings of Series 12, the erosion sensor holders for Stations B and D could not be removed from the tube caused by binding. Firings continued without these erosion sensors.

MAG = 300X

SERIES 0 NO ADDITIVE
AFTER 4 SHOTS



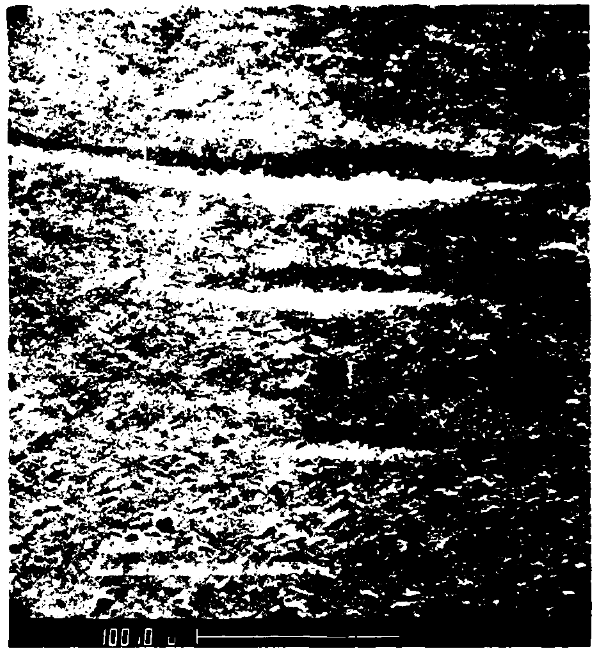
MAG = 300X

SERIES 1 STD LINER
AFTER 4 SHOTS

Figure 8 TYPICAL EFFECT OF WEAR ADDITIVE AT THE MINIMUM WEAR STATION

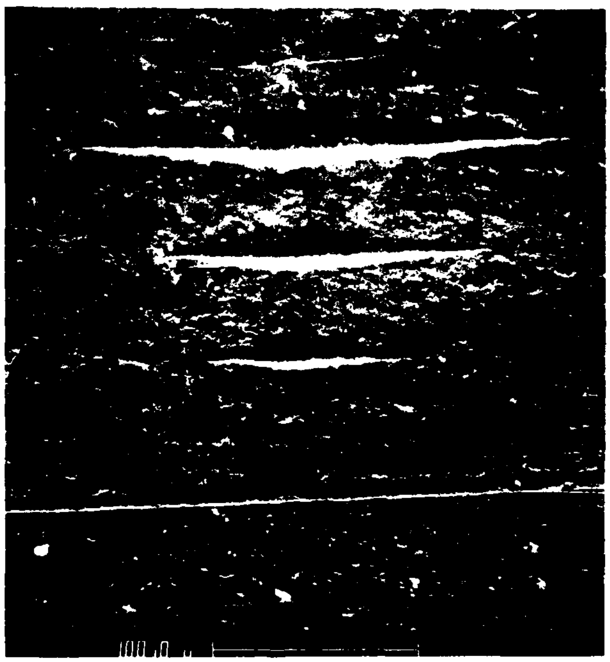
SEVERE LOSS

SERIES 0 NO ADDITIVE
AFTER 4 SHOTS



MODERATE LOSS

SERIES 1 STD LINER
AFTER 4 SHOTS



SMALL LOSS

SERIES 9 KERR-MC GEE
LINER AFTER 4 SHOTS

Figure 9 EFFECT OF ADDITIVE AND TYPE ON LAND EROSION AT THE ORIGIN

bore heating and, therefore, erosion. Heating/erosion correlation for the origin of rifling and the secondary wear station were made and are shown in Figures 10 and 11. These correlations were derived by simply plotting the observed ranking of each charge type based upon erosion versus its ranking based upon heating. The resulting points were treated to find the best least squares fit using a linear regression technique. As shown in the figures, the resulting slopes of the linear curve fits of the points are nearly unity which shows a very good correlation. There are obviously some points far removed from the curve and the cause of these isolated variances is as yet unknown, but it is clear that bore heating plays a major role in tube erosion/wear. Furthermore, the combined instrumentation techniques applied in this study are effective in comparing ammunition modifications with regard to tube erosion/wear characteristics.

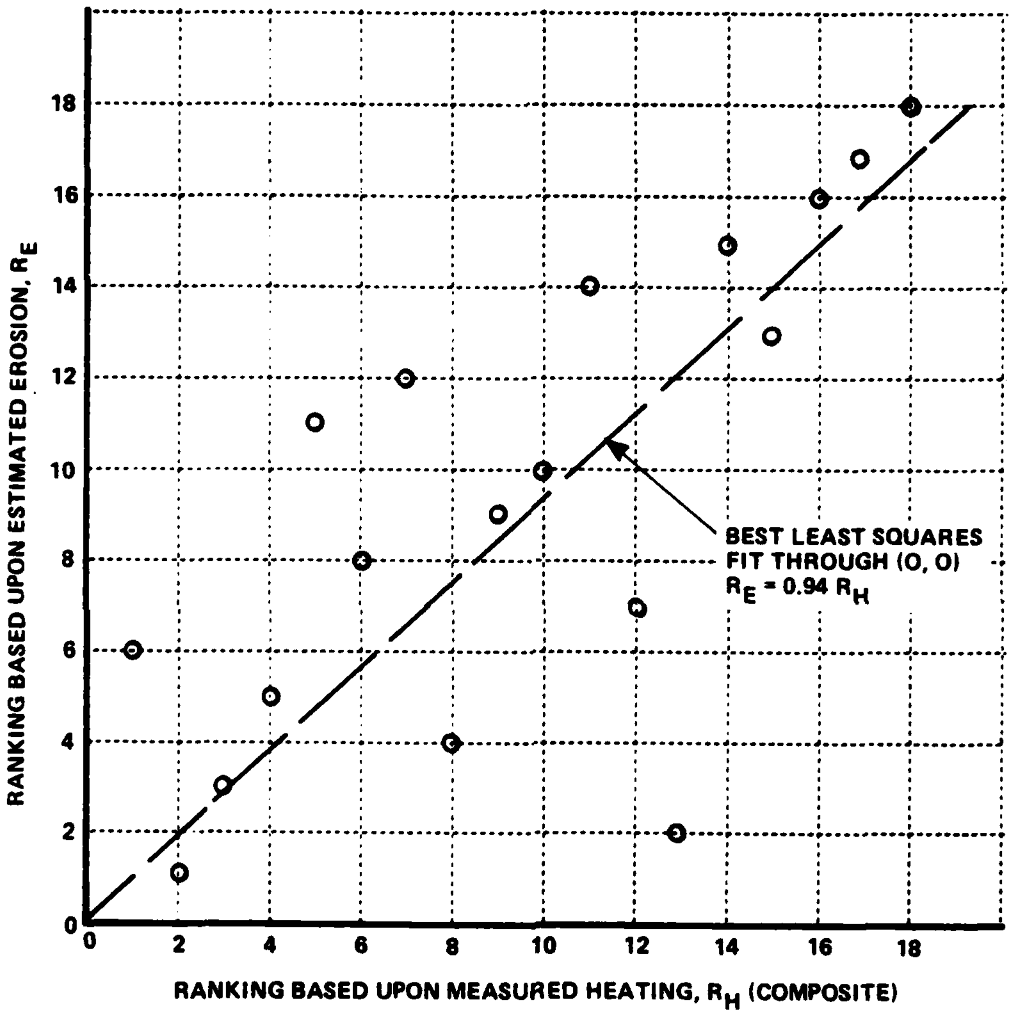


Figure 10 HEATING/EROSION CORRELATION BASED UPON ESTIMATED RANKINGS AT THE ORIGIN OF RIFLING

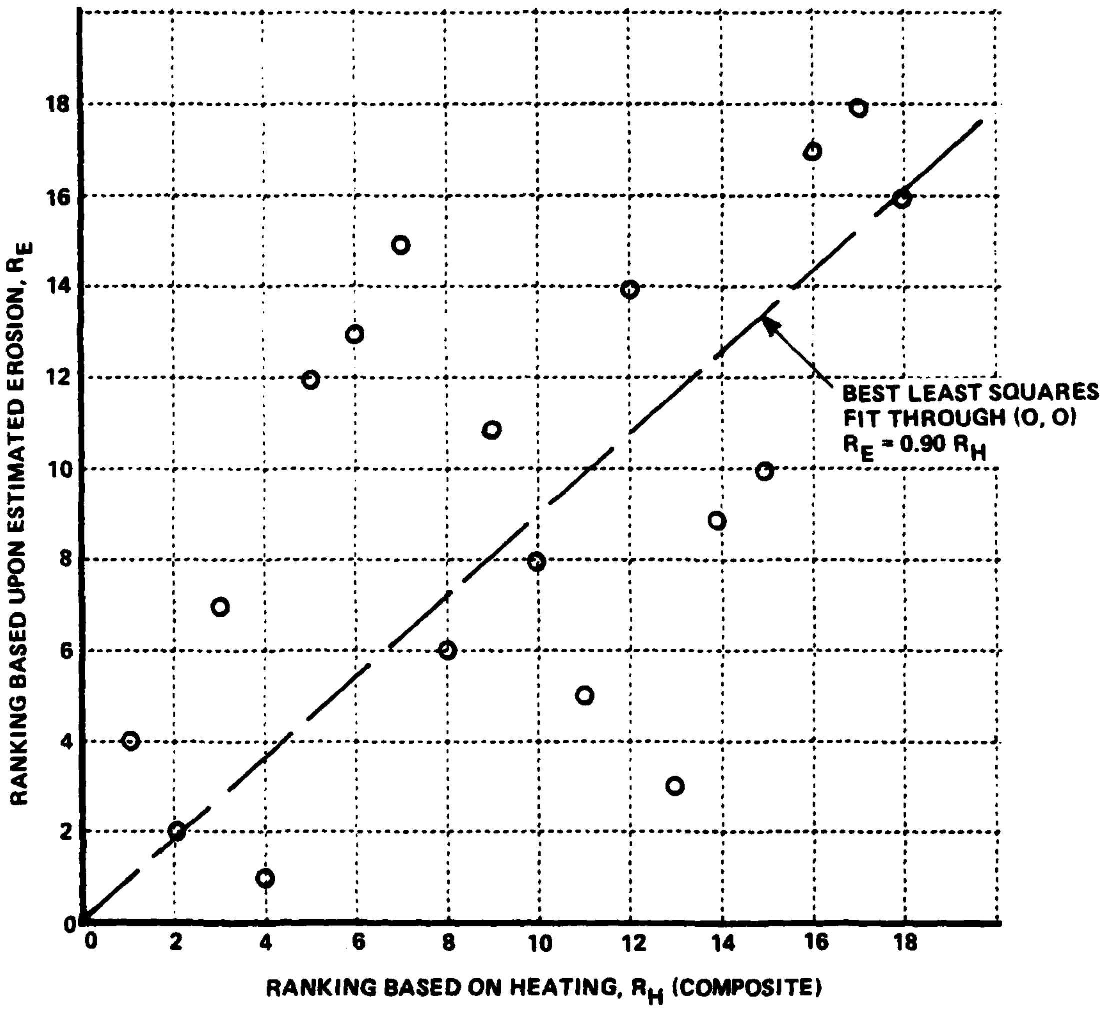


Figure 11 HEATING/EROSION CORRELATION BASED UPON ESTIMATED RANKINGS AT THE SECONDARY WEAR STATION

5. CONCLUSIONS AND RECOMMENDATIONS

Through the application of special thermal and erosion sensing methods described in the body of this report, the effectiveness toward reducing tube erosion selected modifications to the M456 charge was determined. Charge variations included those due to changes in additive construction, type, deployment, and amount as well as change in projectile obturation. A relative ranking of charge modifications on the basis of measured bore heating and sensed erosion revealed that:

1. Measurable differences in both heating and erosion can be produced with change in wear reducing additives.

2. All wear reducing additives demonstrated reduction in bore heating over that of charges containing no additive.

3. For the additive charges taken as a group there appears to be higher heating at 10 inches down-bore from the origin than at the origin itself. Furthermore, there is, in fact, evidence of a minimum heating zone between these positions.

4. For some additive types, notably the ablative configurations, there appears to be a marked reduction in heating for subsequent shots, thus indicating significant residual effects of the additive.

5. Generalized ranking of charge modifications indicates that best erosion performance would be gained by the use of ablative type of erosion inhibitors. Among the additive liner groups, results show that a forward liner placement with increased amount of additive is desirable.

6. Both heating and erosion results suggest that measurable differences in erosion protection are associated with change in type of TiO_2 used. For example, the TiO_2 supplied by Kerr-McGee outperformed the other TiO_2 compositions tested.

7. Use of talc in place of TiO_2 appears to result in improved thermal/erosion performance.

8. There appears to be a definite correlation between measured bore heating and erosion at each station. The correlation is not absolute, however, in that there are isolated variances where the measured heating is in opposition to the measured erosion. These variances may possibly be attributed to the relatively localized areas over which both heating and erosion are measured and the few shots over which the average is taken. Discrepancies are further enhanced by the possible nonlinearity of the erosion exhibited by the sensors as shots are fired. That is, the erosion sensor measurement is essentially an average over the total shots fired. Greater or less erosion could have occurred on the first shot than the last depending upon the tenacity of bore coating developed. Increase in the number of shots fired for each evaluation would improve the averaging technique. Furthermore, an increase in the number of sensed positions at any axial station might overcome the effects of localized placement.

As a result of the tests reported, it is recommended that:

1. The ablative configuration be given further evaluation in an optimization program aimed at

a determination of amounts, compositions, and containments most practical and effective for use as an erosion inhibitor for the M456A1 round.

2. Replacement of the TiO_2 component with talc in the conventional sheet additive be explored through continued testing similar to that of this work.

3. Further improvement of the erosion sensing technique be sought within the above recommended testing. Possible improvements include:

   a). Protection of the sensor edges by use of an outer housing fabricated of a refractory metal alloy such as tantalum-10% tungsten. This outer housing may or may not be firmly attached to the steel sensor itself. The chief benefit of edge protection is to avoid ambiguities in interpretation of erosion sensor loss caused by upstream material loss from the edges reattached in the area of the Knoop impressions. Furthermore, with edge protection, the use of the radioactive isotope technique now becomes feasible.

   b). Combination of both the Knoop sensing and the radioactive isotope sensing techniques within the same sensor system. This will allow both study of surface effects through SEM analysis and direct loss determination through radiation methods.

5. REFERENCES

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